Using NASA "A-Train" Observations for IPCC AR5 climate model evaluations

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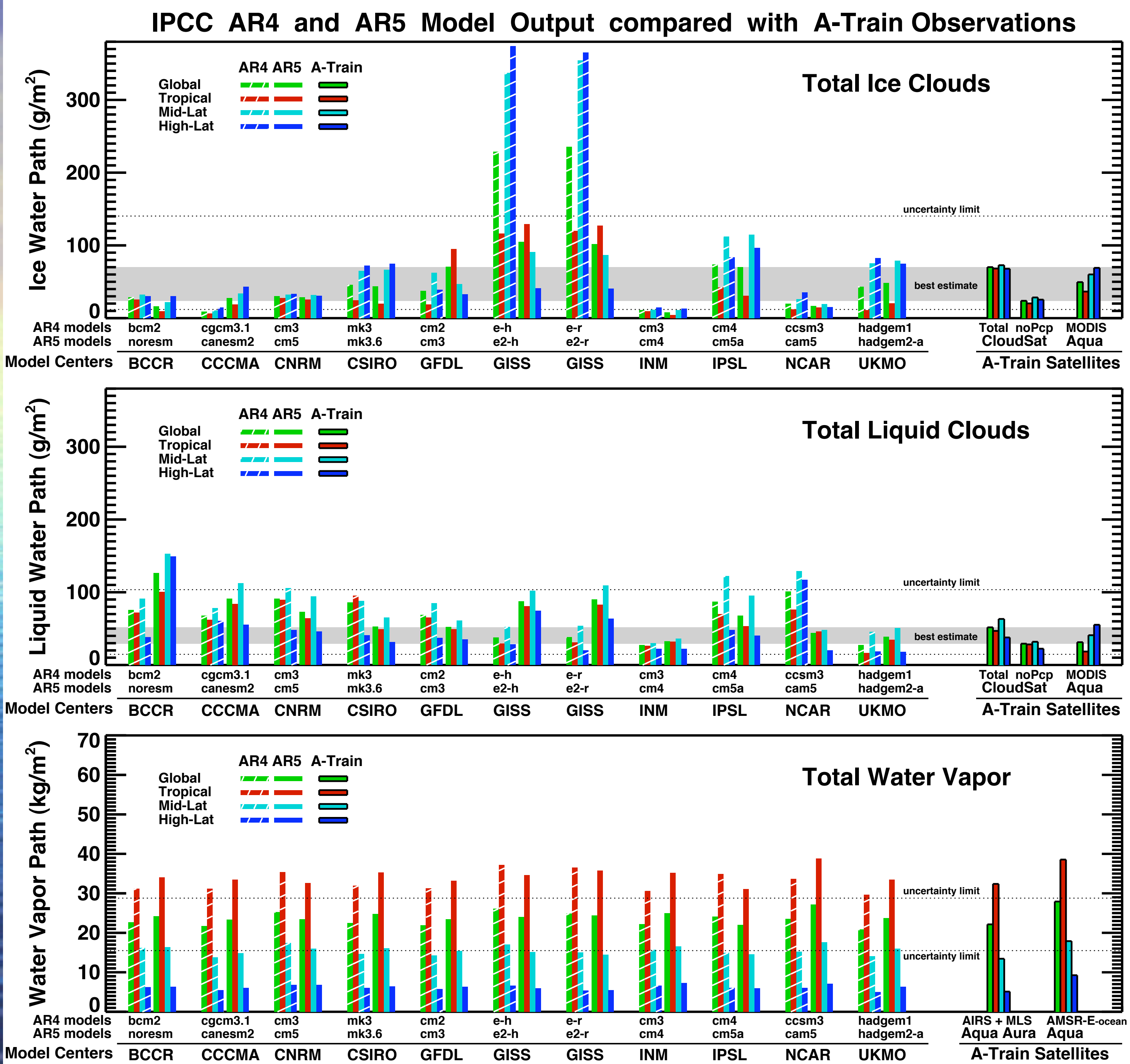
The Project

- **Objective:** To evaluate model simulation results using NASA A-Train data sets and thus contribute to the IPCC AR5.
  - Focus on model performance in simulating clouds and water vapor
    1. Evaluation of climatological annual mean model output
       - Global and latitudinal means and spatial maps of column-integrated cloud water and water vapor paths;
       - Vertical profiles of clouds and water vapor
       - Quantitative evaluations of model performances in simulating spatial means, variances and correlations of tropical clouds and water vapor over the oceans.
    2. Focus physical processes related to clouds and water vapor
       - Examine relationships among clouds, water vapors, temperature and large scale parameters (e.g. SST, CAPE, precipitation, omega velocity, etc.)
  - Examine radiative balance, 2xCO2 projections, clouds and water vapor feedbacks, etc, etc.

Available IPCC AR4/AR5 models

No.	Modeling Center	Acronym	AR4 Model	AR5 Model Now available on ESG	Note
1	Beijing Climate Center, China	BCC	csm1	csm1.1	AR4 cloud data not available on CMIP3
2	Bjerknes Centre for Climate Research, Norway	BCCR	bcm2	noresm1	
3	Canadian Centre for Climate Modeling & Analysis, Canada	CCCMA	cgcm3.1	am4, cm4, canesm2	
4	Centre National de Recherches Météorologiques, France	CNRM	cm3	cm5	
5	Australia's Commonwealth Scientific & Industrial Research Organization, Australia	CSIRO	mk3	mk3.6	
6	Geophysical Fluid Dynamics Laboratory, USA	GFDL	cm2	am3, cm3	AR5 data prepared by Charles Seman
7	Goddard Institute for Space Studies, NASA, USA	GISS	e-h, e-r, aom	e2-h, e2-r	
8	Institute of Atmospheric Physics, China	IAP	fgoals-g1	fgoals-g2	
9	Institute for Numerical Mathematics, Russia	INM	cm3	cm4	
10	Institut Pierre Simon Laplace, France	IPSL	cm4	cm5a	AR5 iwp/lwp, iwc/lwc data not available yet
11	Meteorological Institute of and University of Bonn & Institute of the Korea, Germany/Korea	MIUB	echo-g	echo-g1	IWP data not available in AR4
12	Max-Planck-Institute for Meteorology, Germany	MPI-M	echam5	echam6	
13	Meteorological Research Institute, Japan	MRI	cgcm2.3.2	cgcm3	AR4 iwp / lwp data not available
14	National Center for Atmospheric Research, USA	NCAR	ccsm3, pcm	cam5 (cesm1)	cesm1 data provide by Andrew Getterman
15	National Institute for Environmental Studies, Japan	NIES	miroc3.2 hires, medres	microc4	AR4 pressure need to switch orders
16	UK Met Office, UK	UKMO	hadgem1, hadcm3	hadgem2-a, hadgem2-es	AR5 daily data
17	Global Modeling and Assimilation Office, Goddard Space Flight Center, USA	GMAO		geos5, merra	Not participated in AR4



Cloud & Water Vapor Paths

11 pairs of AR4 and AR5 models are shown here

IWP

For global mean, **6** AR5 models simulate IWPs agree with observational best estimates; **10** AR5 model (except INM cm4) produce IWPs within the observational uncertainty limits.

For AR4 models, the number was **5** and **7**.

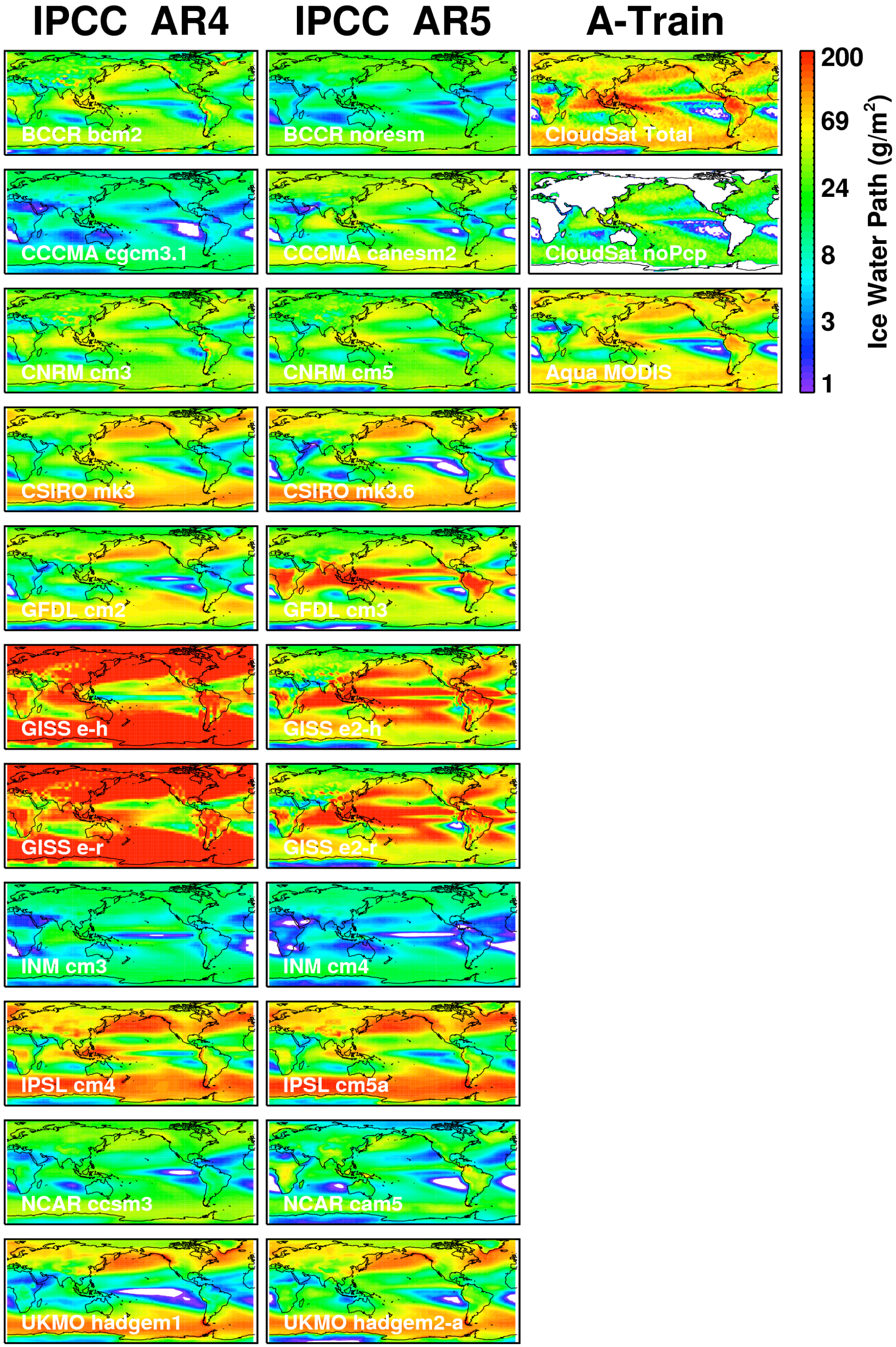
LWP

For global mean, **4** AR5 models simulated LWPs within the obs. best estimates; **10** AR5 models (except BCCR noresm) produce LWPs fall within observational uncertainty.

For AR4 models, the number was **2** and **11**.

H_2O

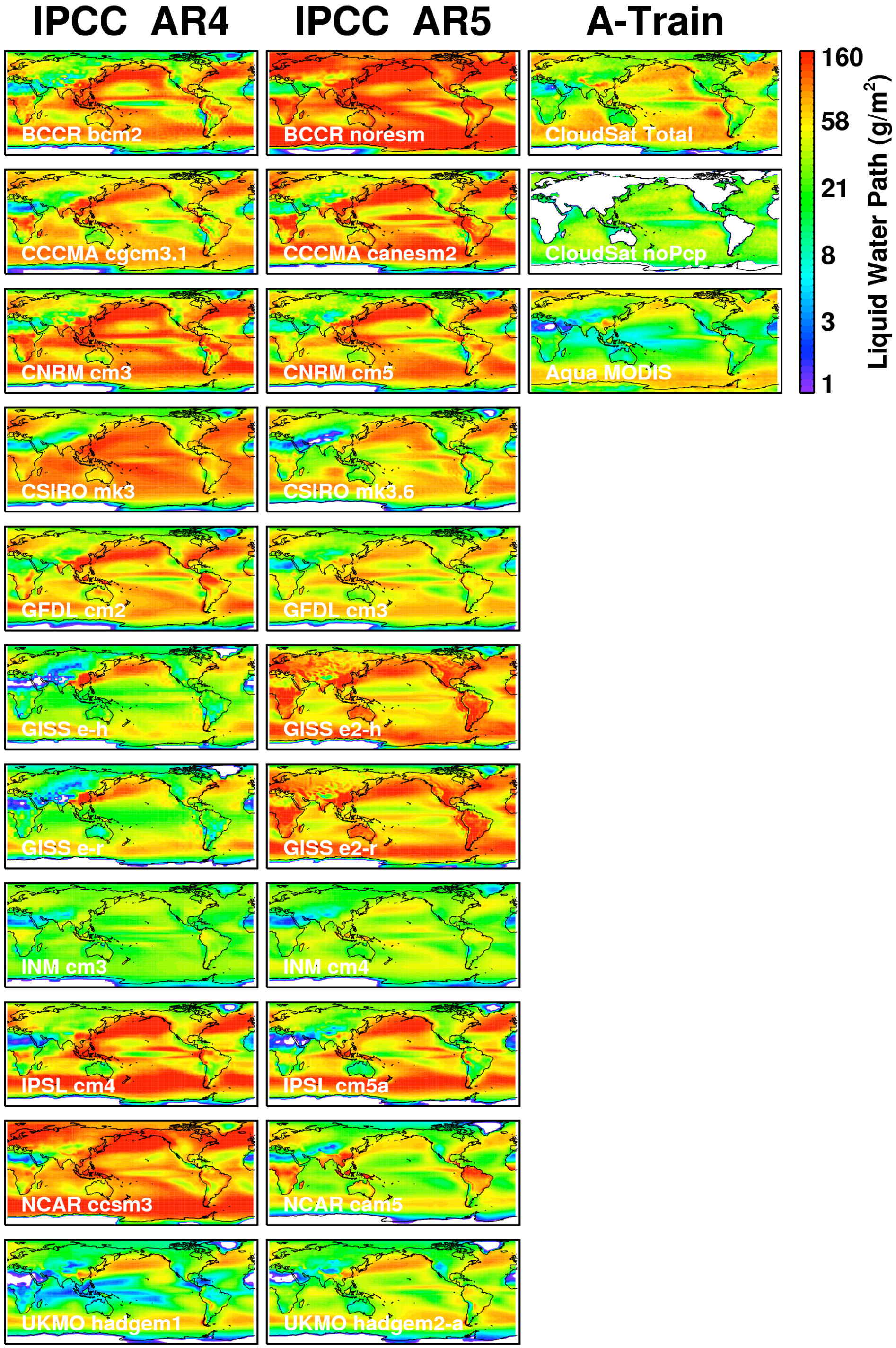
Global mean model-model and model-observation agreements within ~20%



IWP Maps

- BCCR bcm2 to noresm: Overall reduction in IWP, resulting in low bias comparing to the observations;
- CCCMA cgcm3.1 to canesm2: Overall enhancement in cloud ice amount resulting in substantial improved agreement with observations;
- CNRM cm3 to cm5: Very little change;
- CSIRO mk3 to CSIRO mk3.6: Slightly reduced cloud ice amount in the tropics resulting in a slight degradation in agreement with observations;
- GFDL cm2 to cm3: IWP increased in the tropics but decrease in the northern hemispheric storm tracks and southern mid- to high latitudes. The AR5 result is in better agreement with observations in the tropics, but is biased low in the mid- to high latitudes.
- GISS e-r(h) to e2-r(h): Substantial reduction in mid and high latitudes and enhancement in the tropics, resulting in better agreement with observations.
- INM cm3 to cm4: Decrease in the equatorial eastern Pacific but increase over the mid-latitude storm tracks. Although the global mean is not significantly changed, the simulation over the inter-tropical convergence zone (ITCZ) is noticeably degraded.
- IPSL cm4 to cm5a: Overall very small changes from AR4 to AR5, although the cloud ice amount in the tropics is seen slightly reduced resulting in some improvement comparing to observations;
- NCAR ccsm3 to cam5: Slightly reduced cloud ice amount over the oceans, but increased cloud ice amount over the landmasses. There is no obvious improvement comparing to observations;
- UKMO hadgem1 to hadgem2-a: Slight increase in ice cloud amount in the tropics, resulting in smaller low bias compared to observations; little changes in the mid- and high latitudes.

Summary: 6 models show IWP improvements from AR4 to AR5, **2** models show little change, while the rest **3** models appear to be degraded.

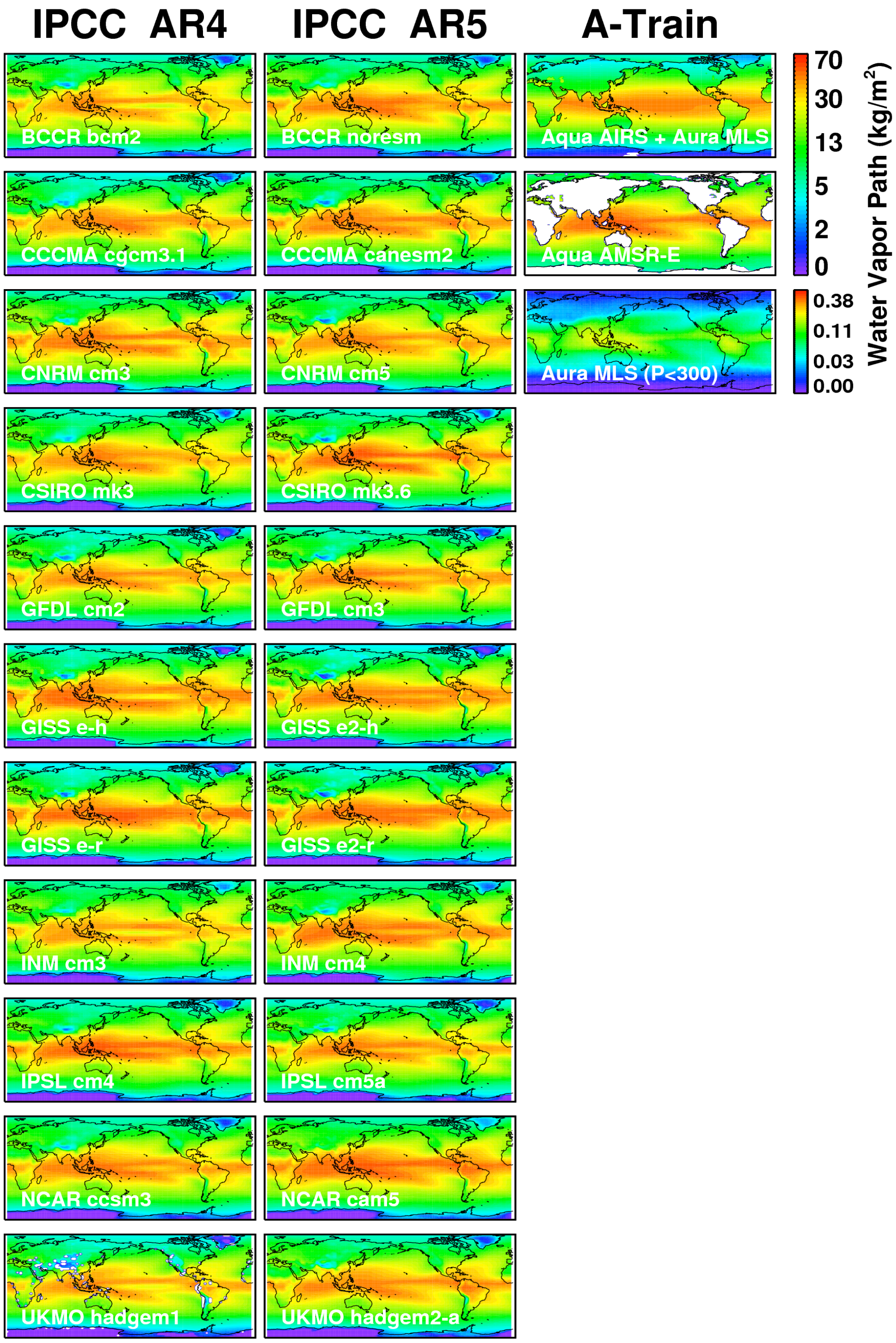


LWP Maps

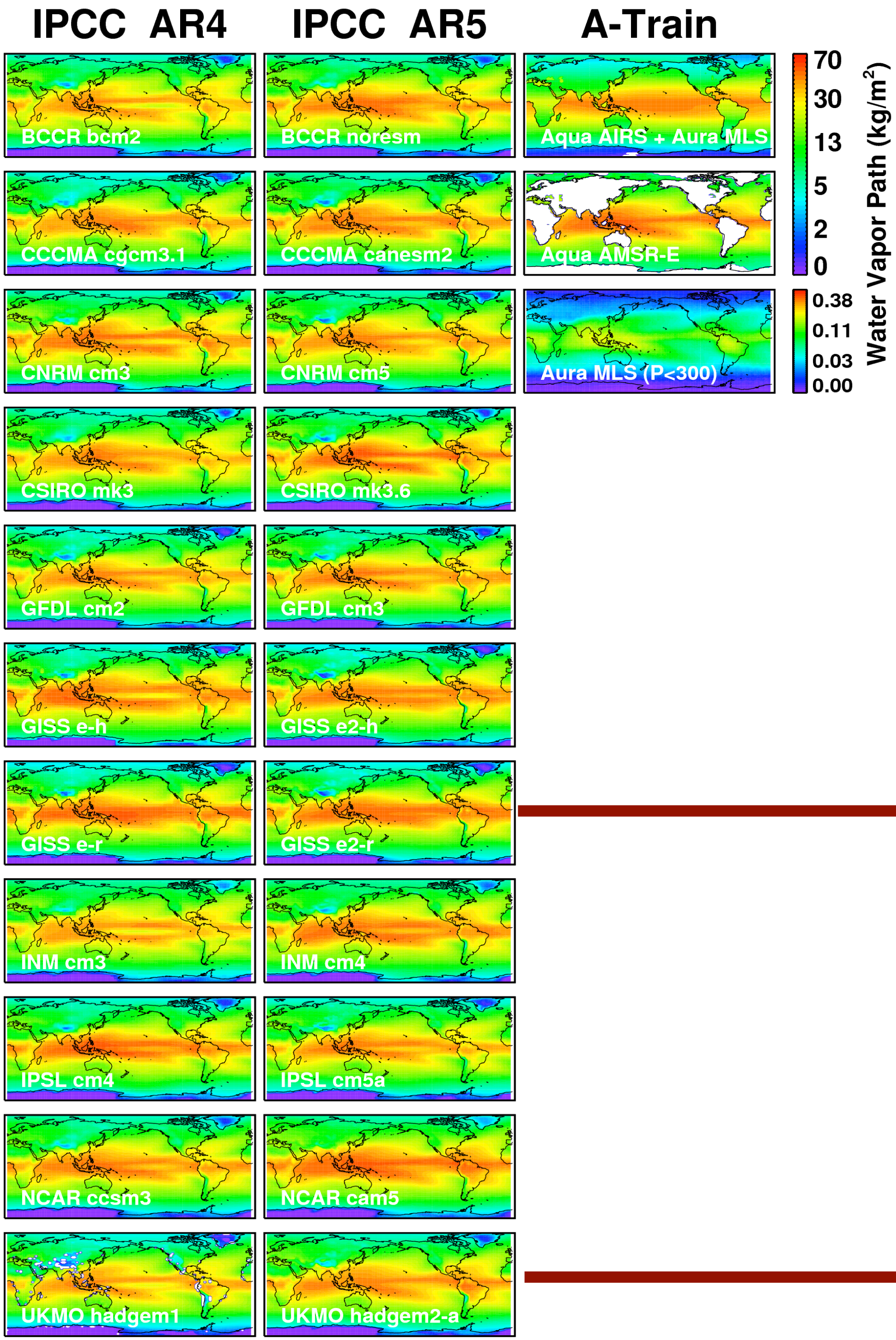
- BCCR bcm2 to noresm: Excessive increase in LWP magnitude leads to significant overestimate of liquid clouds in AR5 version;
- CCCMA cgcm3.1 to canesm2: Excessive increase in LWP magnitude and double "ITCZ" in the equatorial Pacific, which result in poorer agreement with the observations;
- CNRM cm3 to cm5: No significant changes except slightly reduced magnitude resulting in slightly improved agreement with the observations. The spatial patterns are remarkably similar to the GFDL models;
- CSRO mk3 to mk3.6: Reduced IWP amount in latitudes resulting substantial improvement in both magnitude and distribution comparing to observations. Also notable is the model's improved simulation of clouds in subsidence region over the eastern Pacific as well as in southern Indian Ocean (west of Australia);
- GFDL cm2 to cm3: the spatial patterns are similar, but the magnitude of LWP is reduced, resulting in closer agreement with the A-Train data. The morphology of LWP in the GFDL models is approximately similar to the observations, but the climatological stratiform clouds near the west coast of Peru are not captured well, especially in the AR5 version (cm3);
- ISS e-h(r) to e2-h(r): Overall increase of liquid cloud amount, more substantial in mid and high latitudes than in the tropics. Compared to the A-Train observations, the spatial distributions are too zonal;
- INM cm3 to cm4: Slightly increased LWP. This is an improvement as closer agreement with observations is made;
- NCAR ccsm3 to cam5: Substantial reduction in LWP amount resulting better agreement with observations;
- UKMO hadgem1 to hadgem2: Increased in liquid cloud amount, resulting in better agreement with observations.

Summary: 8 models show LWP improvements from AR4 to AR5, **1** model shows little change, while the rest **2** models appear degraded.

WVP Maps



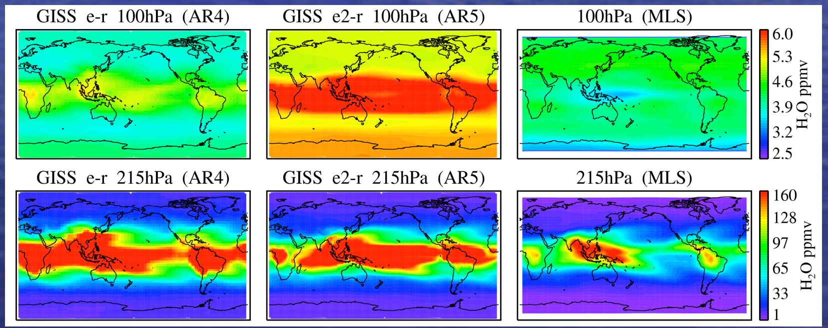
Summary: The inter-model and model-observation differences are relatively small. Since the variability of WVP is dominated by lower-tropospheric water vapor, it is expected that the simulated lower tropospheric water vapor is similar among models, while large discrepancy may exist in the upper troposphere.

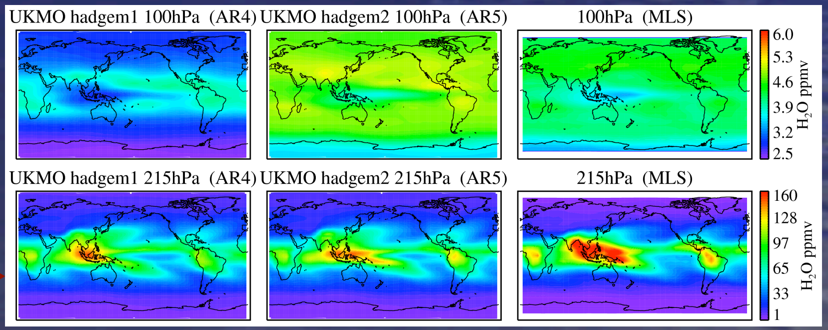


WVP Maps

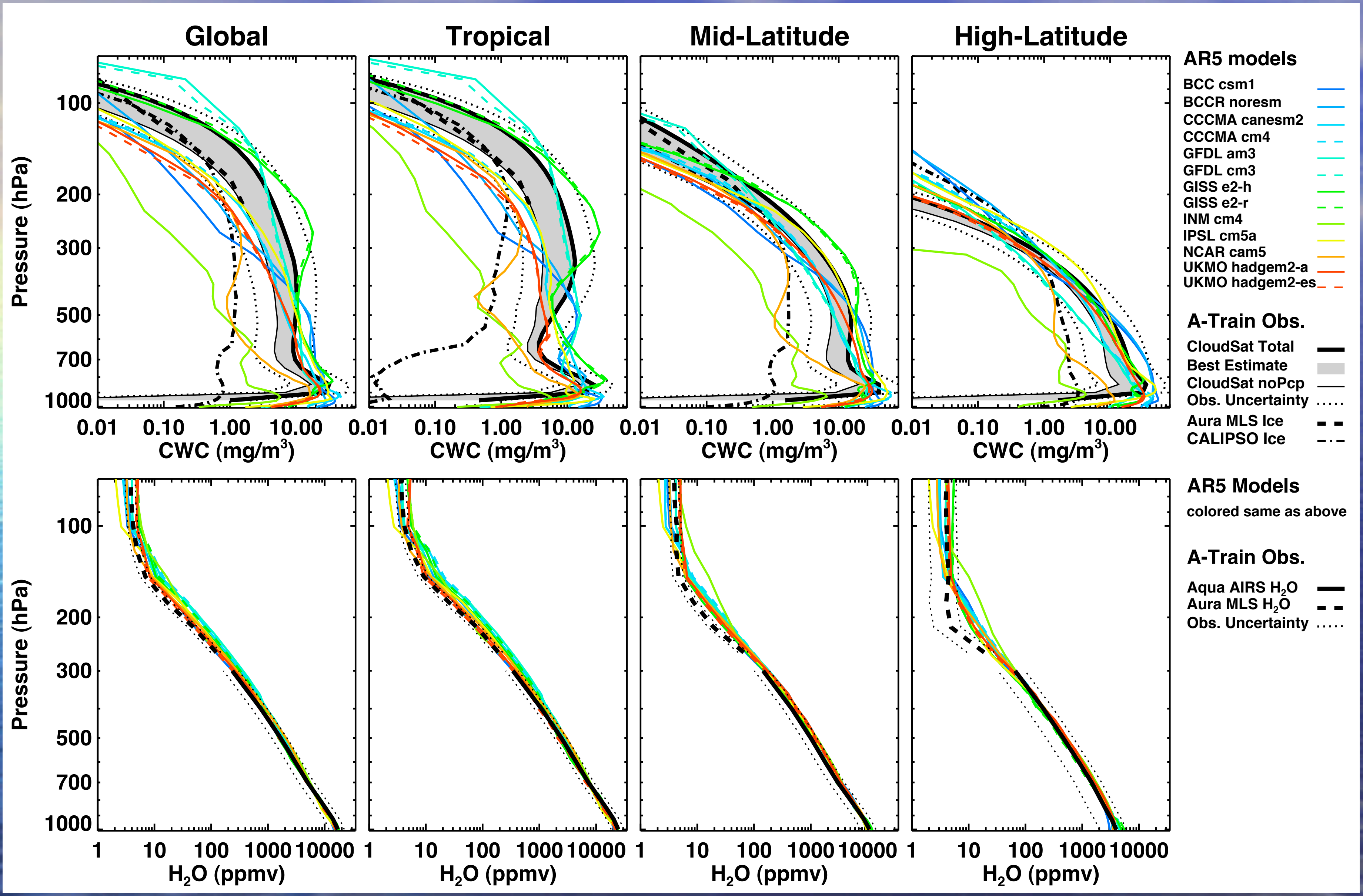
Summary: The inter-model and model-observation differences are relatively small. Since the variability of WVP is dominated by lower-tropospheric water vapor, it is expected that the simulated lower tropospheric water vapor is similar among models, while large discrepancy may exist in the upper troposphere.

Upper troposphere H_2O Maps





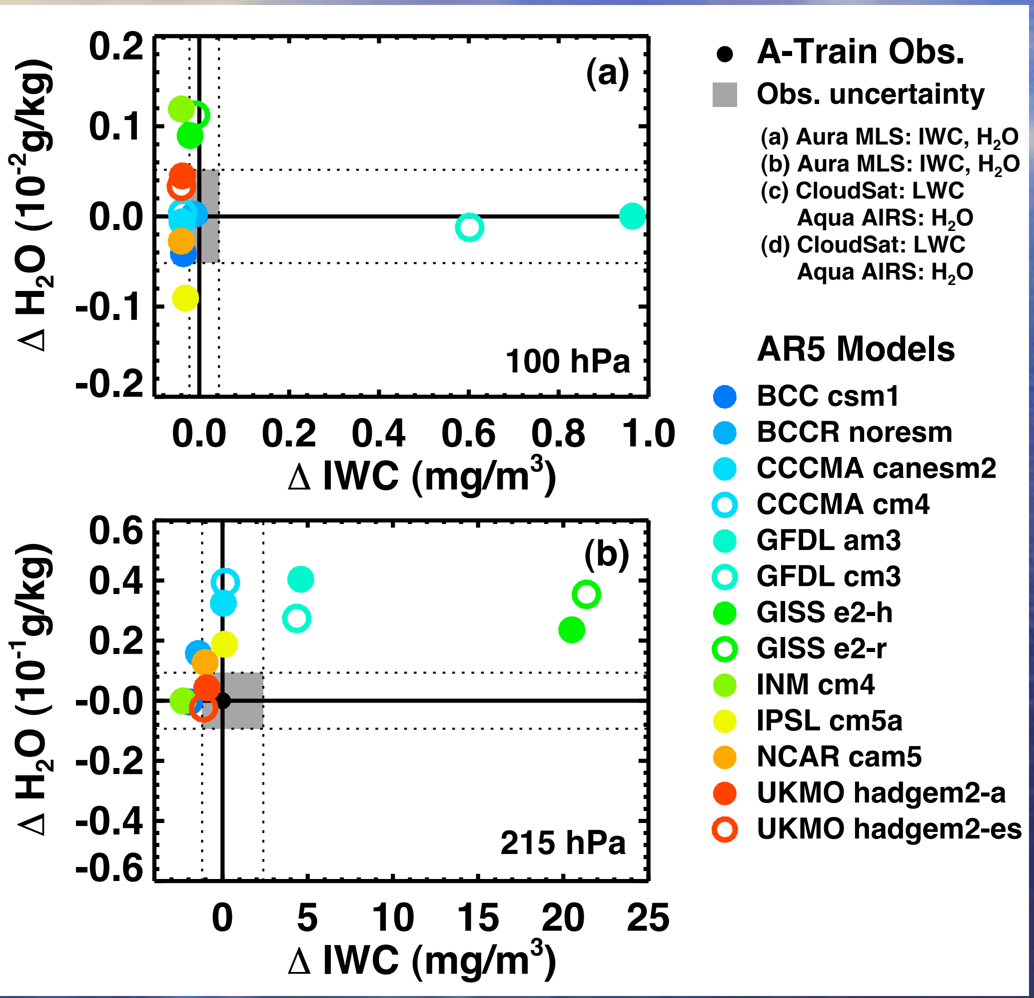
Vertical Profiles



CWC: Modeled CWCs have a large spread at all altitudes, and more than factor of ~200 spread above 300 hPa altitude

H_2O: Modeled H_2Os show increasing spread in upper troposphere

A Metric Based on MLS Observations



The grading system

$$G_m^{iwc,lwc} = \max\left[0, 1 - \frac{1}{n_g}\frac{\left|\ln(m_{mdl}^{iwc,lwc}) - \ln(m_{obs}^{iwc,lwc})\right|}{\ln \sigma_m^{iwc,lwc}}\right]$$

$$G_m^{h_2o} = \max\left[0, 1 - \frac{1}{n_g}\frac{\left|m_{mdl}^{h_2o} - m_{obs}^{h_2o}\right|}{\sigma_m^{h_2o} m_{obs}^{h_2o}}\right]$$

To quantitatively evaluate model performance, we develop a grading system that broadly categorizes the degree to which each model reproduces observed spatial mean and variance (standard deviation) as well as spatial correlation between models and observations.

(a): Obs. 100 hPa: $\overline{IWC}$ = 0.0438 (0.0219-0.0875) **g/m³**

No.	AR5 Models	$\overline{IWC}$ (mg/m³)	G_m^{iwc}	Grade
1	BCC csm1	0.00851	0.764	C
2	BCCR noresm	0.0328	0.958	A
3	CCCMA canesm2	0.00523	0.693	D
4	CCCMA cm4	0.00658	0.727	C
5	GFDL am3	1.01	0.547	F
6	GFDL cm3	0.646	0.612	D
7	GISS e2-h	0.0234	0.909	A
8	GISS e2-r	0.0354	0.969	A
9	INM cm4	0.00393	0.652	D
10	IPSL cm5a	0.0133	0.828	B
11	NCAR cam5	0.00356	0.638	D
12	UKMO hadgem2-a	0.00607	0.715	C
13	UKMO hadgem2-es	0.00389	0.651	D

(b): Obs. 215 hPa: $\overline{IWC}$ = 2.39 (1.20-4.78) **mg/m³**

No.	AR5 Models	$\overline{IWC}$ (mg/m³)	G_m^{iwc}	Grade
1	BCC csm1	0.460	0.762	C
2	BCCR noresm	0.974	0.871	B
3	CCCMA canesm2	2.44	0.997	A
4	CCCMA cm4	2.56	0.990	A
5	GFDL am3	6.98	0.845	B
6	GFDL cm3	6.75	0.850	B
7	GISS e2-h	22.9	0.674	D
8	GISS e2-r	23.8	0.669	D
9	INM cm4	0.0729	0.497	F
10	IPSL cm5a	2.51	0.993	A
11	NCAR cam5	1.37	0.920	A
12	UKMO hadgem2-a	1.47	0.930	A
13	UKMO hadgem2-es	1.28	0.910	A

(a): Obs. 100 hPa: $\overline{H_2O}$ = 0.259 (±0.0259)10^{-2} **g/kg**

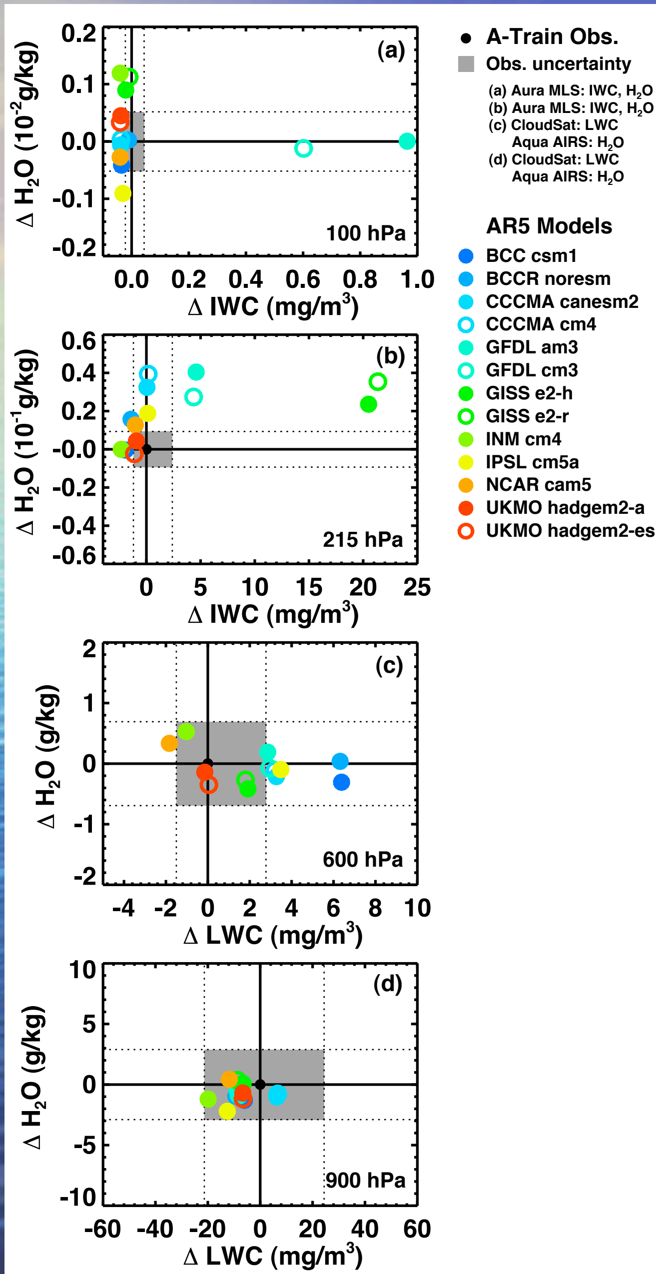
No.	AR5 Models	$\overline{H_2O}$ (10^{-2} g/kg)	G_m^{h2o}	Grade
1	BCC csm1	0.217	0.920	A
2	BCCR noresm	0.261	0.995	A
3	CCCMA canesm2	0.253	0.988	A
4	CCCMA cm4	0.262	0.993	A
5	GFDL am3	0.259	0.999	A
6	GFDL cm3	0.247	0.977	A
7	GISS e2-h	0.348	0.827	B
8	GISS e2-r	0.371	0.783	C
9	INM cm4	0.378	0.770	C
10	IPSL cm5a	0.168	0.825	B
11	NCAR cam5	0.231	0.947	A
12	UKMO hadgem2-a	0.304	0.913	A
13	UKMO hadgem2-es	0.292	0.936	A

(b): Obs. 215 hPa: $\overline{H_2O}$ = 0.466 (±0.0932)10^{-1} **g/kg**

No.	AR5 Models	$\overline{H_2O}$ (10^{-1} g/kg)	G_m^{h2o}	Grade
1	BCC csm1	0.462	0.996	A
2	BCCR noresm	0.623	0.832	B
3	CCCMA canesm2	0.791	0.652	D
4	CCCMA cm4	0.860	0.578	F
5	GFDL am3	0.871	0.566	F
6	GFDL cm3	0.740	0.706	C
7	GISS e2-h	0.702	0.747	C
8	GISS e2-r	0.820	0.621	D
9	INM cm4	0.466	0.999	A
10	IPSL cm5a	0.654	0.799	C
11	NCAR cam5	0.593	0.864	B
12	UKMO hadgem2-a	0.510	0.954	A

Jiang, Su, Zhai, Perun et al. in preparation, 2011.

Metrics Based on A-Train Observations

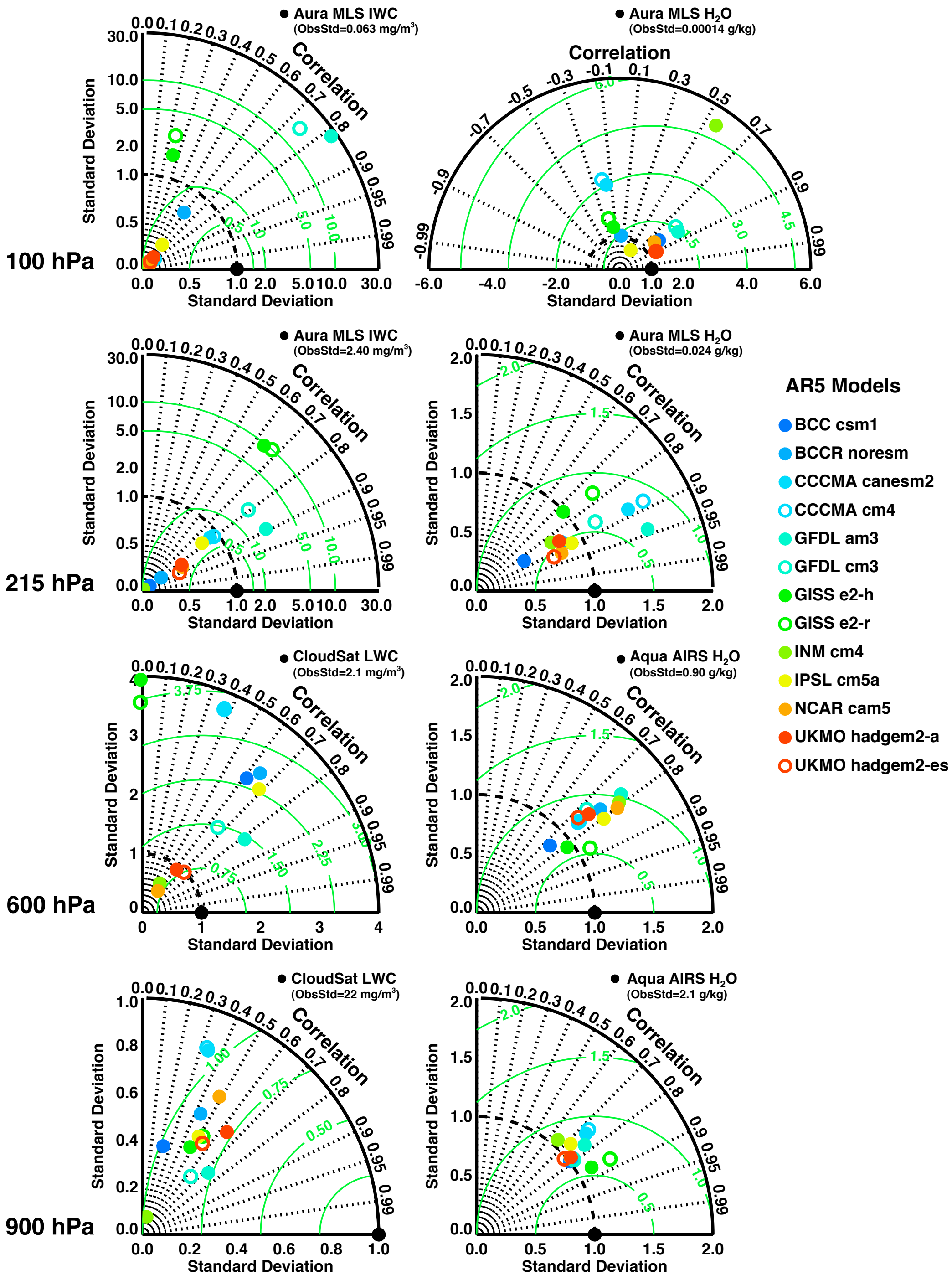


Quantitative evaluation for model simulated tropical mean IWC/LWC and H_2O

Table 4c: Final Grades for AR5 Models simulated tropical mean IWC/LWC and H_2O

No.	AR5 Models	Pressure (hPa)	Grade$^{I/LWC}$	Grade^{H2O}	BVM Grade	Final Grade^{mean}
1	BCC csm1	100: Tropopause	C	A	B- (2.5)	B+ 3.25
		215: Upper trop.	C	A	B (3.0)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
2	BCCR noresm	100: Tropopause	A	A	A (4.0)	A– 3.63
		215: Upper trop.	B	B	B (3.0)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
3	CCCMA canesm2	100: Tropopause	D	A	B- (2.5)	B+ 3.13
		215: Upper trop.	A	D	B- (2.5)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
4	CCCMA cm4	100: Tropopause	C	A	B (3.0)	B+ 3.13
		215: Upper trop.	A	F	C (2.0)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
5	GFDL am3	100: Tropopause	F	A	C (2.0)	B– 2.75
		215: Upper trop.	B	F	C- (1.5)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
6	GFDL cm3	100: Tropopause	D	A	B- (2.5)	B+ 3.13
		215: Upper trop.	B	C	B- (2.5)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
7	GISS e2-h	100: Tropopause	A	B	B- (2.5)	B 3.00
		215: Upper trop.	D	C	C- (1.5)	
		600: Mid-trop.	A	A	A (4.0)	
		900: Boundary layer	A	A	A (4.0)	
8	GISS e2-r	100: Tropopause	A	C	C (2.0)	B– 2.75
		215: Upper trop.	D	D	D (1.0)	
		600: Mid-trop.	A	A	A (4.0)	
		900: Boundary layer	A	A	A (4.0)	
9	INM cm4	100: Tropopause	D	C	D- (0.5)	B– 2.5
		215: Upper trop.	F	A	C (2.0)	
		600: Mid-trop.	A	A	A (4.0)	
		900: Boundary layer	B	A	A- (3.5)	
10	IPSL cm5a	100: Tropopause	B	B	C (2.0)	B+ 3.13
		215: Upper trop.	A	C	B (3.0)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
11	NCAR cam5	100: Tropopause	D	A	C (2.0)	B+ 3.25
		215: Upper trop.	A	B	A- (3.5)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	A	A	A (4.0)	
12	UKMO hadgem2-a	100: Tropopause	C	A	B- (2.5)	A– 3.63
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	A	A	A (4.0)	
		900: Boundary layer	A	A	A (4.0)	
13	UKMO hadgem2-es	100: Tropopause	D	A	C (2.0)	A– 3.50
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	A	A	A (4.0)	
		900: Boundary layer	A	A	A (4.0)	

Final Grade: A=4 (excellent); **B=3** (very good); **C=2** (good); **D=1** (fair); **F=0** (fail)



Taylor Diagrams

- **900 hPa**
  - IWC: stddev < Obs; corr 0.1 to 0.8
  - H_2O: stddev > Obs; corr 0.2 to 0.8
- **600 hPa**
  - IWC: stddev 0.4 to 4; corr −0.03 to 0.8
  - H_2O: stddev 0.8 to 1.5; corr 0.7 to 0.9
- 215 hPa:
  - IWC: stddev 0.1 to 10; corr 0.6 to 0.9
  - H_2O: stddev 0.5 to 1.6; corr 0.7 to 0.9
- 100 hPa:
  - IWC: stddev 0.1 to 28; corr 0.2 to 0.8
  - H_2O: stddev 0.3 to 5; corr -0.3 to 0.9

Quantitative evaluation for model simulated IWC/LWC and H_2O in terms of:

Spatial Correlation

Table 5c: Final Grades for AR5 Models simulated spatial correlation of IWC/LWC and H_2O with A-Train observations

No.	AR5 Models	Pressure (hPa)	$Grade^{I/LWC}$	$Grade^{H2O}$	BVM Grade	Final $Grade^{corr}$
1	BCC csm1	100: Tropopause	B	A	A- (3.5)	B+ 3.13
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	B	B	B (3.0)	
		900: Boundary layer	D	B	C (2.0)	
2	BCCR noresm	100: Tropopause	C	F	D (1.0)	B- 2.63
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	B	B	B (3.0)	
		900: Boundary layer	C	B	B- (2.5)	
3	CCCMA canesm2	100: Tropopause	B	F	C- (1.5)	B– 2.38
		215: Upper trop.	B	A	A- (3.5)	
		600: Mid-trop.	D	B	C (2.0)	
		900: Boundary layer	C	B	B- (2.5)	
4	CCCMA cm4	100: Tropopause	B	F	C- (1.5)	C+ 2.25
		215: Upper trop.	B	A	A- (3.5)	
		600: Mid-trop.	D	B	C (2.0)	
		900: Boundary layer	D	B	C (2.0)	
5	GFDL am3	100: Tropopause	A	A	A (4.0)	A– 3.63
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	A	B	A- (3.5)	
		900: Boundary layer	B	B	B (3.0)	
6	GFDL cm3	100: Tropopause	B	B	B (3.0)	B+ 3.13
		215: Upper trop.	B	A	A- (3.5)	
		600: Mid-trop.	B	B	B (3.0)	
		900: Boundary layer	B	B	B (3.0)	
7	GISS e2-h	100: Tropopause	D	F	D- (0.5)	C+ 2.13
		215: Upper trop.	B	B	B (3.0)	
		600: Mid-trop.	F	A	C (2.0)	
		900: Boundary layer	C	A	B (3.0)	
8	GISS e2-r	100: Tropopause	D	F	D- (0.5)	C+ 2.13
		215: Upper trop.	B	B	B (3.0)	
		600: Mid-trop.	F	A	C (2.0)	
		900: Boundary layer	C	A	B (3.0)	
9	INM cm4	100: Tropopause	C	C	C (2.0)	C+ 2.38
		215: Upper trop.	C	A	B (3.0)	
		600: Mid-trop.	C	B	B- (2.5)	
		900: Boundary layer	D	B	C (2.0)	
10	IPSL cm5a	100: Tropopause	B	C	B- (2.5)	B 3.00
		215: Upper trop.	B	A	A- (3.5)	
		600: Mid-trop.	B	A	A- (3.5)	
		900: Boundary layer	C	B	B- (2.5)	
11	NCAR cam5	100: Tropopause	A	B	A- (3.5)	B+ 3.25
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	C	A	B (3.0)	
		900: Boundary layer	C	B	B- (2.5)	
12	UKMO hadgem2-a	100: Tropopause	B	A	A- (3.5)	B+ 3.38
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	B	B	B (3.0)	
		900: Boundary layer	B	B	B (3.0)	
13	UKMO hadgem2-es	100: Tropopause	B	A	A- (3.5)	B+ 3.25
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	B	B	B (3.0)	
		900: Boundary layer	C	B	B- (2.5)	

Final Grade: **A=4** (excellent); **B=3** (very good); **C=2** (good); **D=1** (fair); **F=0** (fail)

Spatial Variation

Table 6c: Final Grades for AR5 Models simulated spatial variance of IWC/LWC and H_2O

No.	AR5 Models	Pressure (hPa)	$Grade^{I/LWC}$	$Grade^{H2O}$	BVM Grade	Final $Grade^{stddev}$
1	BCC csm1	100: Tropopause	C	B	B- (2.5)	C+ 2.38
		215: Upper trop.	D	B	C (2.0)	
		600: Mid-trop.	F	A	C (2.0)	
		900: Boundary layer	C	A	B (3.0)	
2	BCCR noresm	100: Tropopause	A	A	A (4.0)	B 3.00
		215: Upper trop.	C	A	B (3.0)	
		600: Mid-trop.	F	B	C- (1.5)	
		900: Boundary layer	B	A	A- (3.5)	
3	CCCMA canesm2	100: Tropopause	C	F	D (1.0)	B– 2.63
		215: Upper trop.	A	B	A- (3.5)	
		600: Mid-trop.	F	A	C (2.0)	
		900: Boundary layer	A	A	A (4.0)	
4	CCCMA cm4	100: Tropopause	C	F	D (1.0)	B– 2.50
		215: Upper trop.	A	B	A- (3.5)	
		600: Mid-trop.	F	B	C- (1.5)	
		900: Boundary layer	A	A	A (4.0)	
5	GFDL am3	100: Tropopause	F	D	D- (0.5)	C– 1.88
		215: Upper trop.	F	B	C- (1.5)	
		600: Mid-trop.	D	A	B- (2.5)	
		900: Boundary layer	C	A	B (3.0)	
6	GFDL cm3	100: Tropopause	F	F	F (0.0)	C– 1.88
		215: Upper trop.	F	A	C (2.0)	
		600: Mid-trop.	D	A	B- (2.5)	
		900: Boundary layer	C	A	B (3.0)	
7	GISS e2-h	100: Tropopause	C	B	B- (2.5)	B– 2.50
		215: Upper trop.	F	A	C (2.0)	
		600: Mid-trop.	F	A	C (2.0)	
		900: Boundary layer	B	A	A- (3.5)	
8	GISS e2-r	100: Tropopause	F	C	D (1.0)	C+ 2.13
		215: Upper trop.	F	A	C (2.0)	
		600: Mid-trop.	F	A	C (2.0)	
		900: Boundary layer	B	A	A- (3.5)	
9	INM cm4	100: Tropopause	D	F	D- (0.5)	C+ 2.13
		215: Upper trop.	D	A	B- (2.5)	
		600: Mid-trop.	B	B	B (3.0)	
		900: Boundary layer	D	A	B- (2.5)	
10	IPSL cm5a	100: Tropopause	C	B	B- (2.5)	B– 2.88
		215: Upper trop.	A	A	A (4.0)	
		600: Mid-trop.	F	B	C- (1.5)	
		900: Boundary layer	B	A	A- (3.5)	
11	NCAR cam5	100: Tropopause	D	B	C (2.0)	B 3.00
		215: Upper trop.	B	A	A- (3.5)	
		600: Mid-trop.	B	B	B (3.0)	
		900: Boundary layer	B	A	A- (3.5)	
12	UKMO hadgem2-a	100: Tropopause	C	A	B (3.0)	A– 3.50
		215: Upper trop.	B	A	A- (3.5)	
		600: Mid-trop.	A	A	A (4.0)	
		900: Boundary layer	B	A	A- (3.5)	
13	UKMO hadgem2-es	100: Tropopause	C	A	B (3.0)	A– 3.50
		215: Upper trop.	B	A	A- (3.5)	
		600: Mid-trop.	A	A	A (4.0)	
		900: Boundary layer	B	A	A- (3.5)	

Final Grade: **A=4** (excellent); **B=3** (very good); **C=2** (good); **D=1** (fair); **F=0** (fail)

Conclusions:

Table 7: Final Grades for AR5 Models simulations of clouds and water vapor

No.	AR5 Models	Grade^{mean}	Grade^{corr}	Grade^{stddev}	FINAL GRADE
1	BCC csm1	B+ 3.25	B+ 3.13	C+ 2.38	**B–** 2.92
2	BCCR noresm	A– 3.63	B- 2.63	B 3.00	**B+** 3.09
3	CCCMA canesm2	B+ 3.13	B– 2.38	B– 2.63	**B–** 2.71
4	CCCMA cm4	B+ 3.13	C+ 2.25	B– 2.50	**B–** 2.63
5	GFDL am3	B– 2.75	A– 3.63	C– 1.88	**B–** 2.75
6	GFDL cm3	B+ 3.13	B+ 3.13	C– 1.88	**B–** 2.72
7	GISS e2-h	B 3.00	C+ 2.13	B– 2.50	**B–** 2.54
8	GISS e2-r	B– 2.75	C+ 2.13	C+ 2.13	**C+** 2.34
9	INM cm4	B– 2.5	C+ 2.38	C+ 2.13	**C+** 2.34
10	IPSL cm5a	B+ 3.13	B 3.00	B– 2.88	**B** 3.00
11	NCAR cam5	B+ 3.25	B+ 3.25	B 3.00	**B+** 3.17
12	UKMO hadgem2-a	A– 3.63	B+ 3.38	A– 3.50	**A–** 3.50
13	UKMO hadgem2-es	A– 3.50	B+ 3.25	A– 3.50	**B+** 3.42

Final Grade: A=4 (excellent); **B=3** (very good); **C=2** (good); **D=1** (fair); **F=0** (fail)

- Using A-Tran observations, we evaluated performances of AR5 model clouds and water vapor simulations in terms of spatial mean, correlation and standard deviation.
- Overall, models simulate spatial means better than correlation and variance. This suggests global (tropical) means are better represented but regional climates are less trustworthy in models.
- Water vapor is better simulated than clouds. Boundary layer water vapor is the best simulated, because of the strong constraint on boundary layer water vapor by SST. 100 hPa water vapor is very poorly represented.
- For spatial means, upper troposphere is worse than lower and middle troposphere. For spatial correlation, 215 hPa (deep convection) is fairly good; 600 and 900 hPa (low clouds) are very bad. For spatial variance, all levels are poorly simulated.
- There is no apparent correlation between model biases in clouds and water vapor. Their “tunings” are decoupled.

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